Eye Glance Behaviors of Ground Control Station Operators in a Simulated Urban Air Mobility Environment

James R. Unverricht
National Institute of Aerospace
Hampton, Virginia
james.unverricht@nasa.gov

Eric T. Chancey
NASA Langley Research Center
Hampton, Virginia
eric.t.chancey@nasa.gov

Michael S. Politowicz
NASA Langley Research Center
Hampton, Virginia
michael.s.politowicz@nasa.gov

Bill K. Buck
NASA Langley Research Center
Hampton, Virginia
bill.k.buck@nasa.gov

Steven C. Geuther
NASA Langley Research Center
Hampton, Virginia
steven.c.geuther@nasa.gov

***Abstract*—Research into concepts such as advanced air mobility (AAM) and urban air mobility (UAM) offers an opportunity for successfully and safely adding new classes of vehicles into the National Airspace System. However, a need exists for research into the human factors associated with these concepts. In this paper, we evaluate the gaze behaviors of three remote ground control station operators (GCSOs) conducting simulated UAM operations. The participants monitored and controlled an unmanned aircraft system (UAS) from pre-flight to landing using ground control station (GCS) software across nine scenarios within a remote UAS operations center at NASA Langley Research Center (LaRC). As this work was exploratory, descriptive statistics were calculated to provide some initial insight into GCSO gaze patterns associated with the GCS display. Scenarios that required the operator to directly interact with an airspace scheduling system off-screen resulted in fewer on-screen glances than scenarios that did not include direct interactions with the off-screen system. After investigating several areas of interest (AOIs) within the GCS display, participants primarily viewed three AOIs: the map, vehicle status, and operations checklist. The results yielded several GCS design and operational improvement recommendations to include: (a) adding altitude information to the vehicle icon, (b) adding additional traffic information, and (c) including additional GCS training, to reduce the need to scan an operations checklist, which would allow allocation of visual attention towards other AOIs.**

***Keywords*— Human Factors, Eye Tracking, Simulation, Unmanned Aircraft System (UAS), Advanced Air Mobility (AAM), Urban Air Mobility (UAM), Vertiports**

I. Introduction

The advanced air mobility (AAM) concept envisions a diverse set of emerging aviation technologies enabling varying mission types designed to transport people and goods throughout complex inter- and intra-urban environments, including the complex and challenging flight environment of Urban Air Mobility (UAM) [1]. One definition of UAM is as a "safe and efficient system for air passenger and cargo transportation within an urban area. It is inclusive of small package delivery and other urban unmanned aircraft system (UAS) services and supports a mix of onboard/ground-piloted and increasingly autonomous operations" [2]. Whereas AAM broadly encompasses missions outside of metropolitan areas and intraregional missions, UAM is a subset of AAM that specifically includes only "local" operations that occur in and around metropolitan, urban areas [3].

To identify and address a portion of the challenges ahead for these emerging AAM concepts, NASA initiated the High Density Vertiplex (HDV) Subproject[1]. A vertiport is defined as an identifiable ground or elevated area, including any buildings, or facilities thereon, used for the vertical takeoff and landing of an aircraft. A vertiplex is defined as multiple vertiports in a local region with interdependent arrival and departure operations. The HDV Subproject is responsible for developing and testing technologies, concepts, and architectures that will support the infrastructure needed for terminal environments around vertiports. Although these technologies, concepts, and architectures will be relevant to a broad set of envisioned AAM operations, the HDV Subproject primarily focuses on use cases related to UAM operations.

A significant aspect supporting this work entails standing up a remote UAS operations center, which will eventually enable a crew of human operators to remotely manage and control multiple highly automated UAS in beyond visual line of sight (BVLOS) conditions. Located at NASA Langley Research Center (LaRC), the Remote Operations for Autonomous Missions (ROAM) UAS Operations Center provides capabilities necessary to support remote operations. The purpose of this current facility is to verify system-in-test software, connectivity, and human performance using a simulated environment to determine design gaps and verify assumptions. However, to understand human performance and

[1] https://www.nasa.gov/aeroresearch/programs/iasp/aam/hdv/description/

the safety considerations within this environment, one must explore the human factors.

One measurement tool that can provide objective physiological data while remaining unobtrusive to the operator is eye tracking. Eye tracking is the measurement of both eye movement and gaze locations across time [4]. By measuring eye movements or gaze behaviors, one can make inferences about the allocation of visual attention [5, 6], workload [7], and other cognitive properties [8].

To support the exploration of human factors within ROAM, three ground control station operators' (GCSOs') gaze behaviors were measured during simulated UAS scenarios. General feedback from participants was elicited during a post study debrief session. This study was built off previous work by Reference [9], which was a human factors assessment for an earlier instantiation of a remote operations center. The current study represents the next step in building out ROAM and refining the systems, configurations, roles and responsibilities, and training of operators within ROAM.

II. Method

A. Participants

Three male GCSOs (M_{age} = 38.00, SD = 6.00) were sampled from NASA LaRC's GCSO personnel. All participation was voluntary. Participants did not receive any direct benefits for participating. This research complied with the American Psychological Association Code of Ethics and was approved by NASA's Institutional Review Board. Informed consent was obtained from each participant.

B. Apparatus

1) ROAM UAS Operations Center. The ROAM UAS Operations Center was used to conduct the simulation and human factors analysis described herein. The room measures approximately 26' by 15.5' with one accessible exit point. An attached control/observation room was also available for observers during the simulated flight operations. A generalized layout for the ROAM UAS Operations Center can be seen in Fig. 1. The design of ROAM and its layout are intended to support workstation areas for operations personnel such as the GCSO, a Range Safety Officer (RSO), and a Simulation Director (SD). In addition to individual workstations, the ROAM UAS Operations Center was equipped with a large-format video wall.

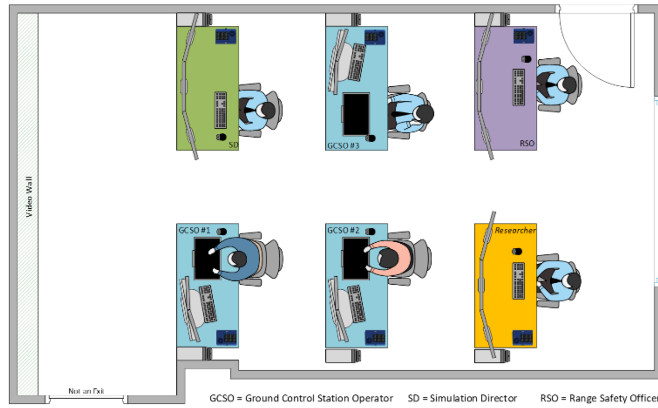

Fig 1. ROAM UAS operations center generalized layout.

2) Ground control station workstation. Fig. 2 presents the layout for the GCSO's workstation. Several guidelines were considered in the workstation design, including keeping the displays of information simple and in a consistent presentation format while facilitating the user's movement among the output sources. It was important that the workstation be easily reconfigurable and interchangeable, dependent on the needs of planned activities.

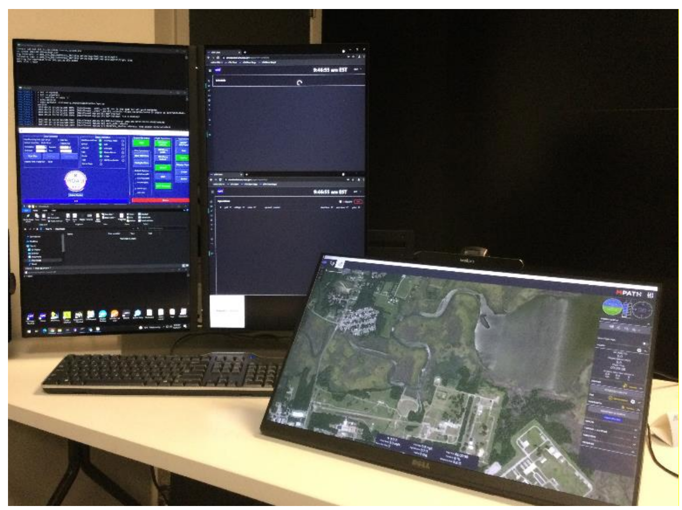
Fig 2. GCSO workstation layout.

3) MPATH. The Measuring Performance for Autonomy Teaming with Humans (MPATH) GCS is a standalone software application developed by NASA for controlling MAVLink-enabled small UAS (see Fig. 3). MPATH is a modified version of the open source QGroundControl software, and it includes several unique features designed to improve software usability and enable AAM and human factors research. The modular widget design consolidates telemetry data into a single area on the display to facilitate close spatial proximity of related information. Direct integration with NASA's vehicle-based automated systems provides automation transparency for GCSOs and researchers. Additionally, MPATH supports routine human factors data collection with the inclusion of an

output file that logs user interaction data. For this study, MPATH was presented on a 24" touchscreen monitor (landscape position), which was tilted at a 45° angle (see Fig. 2). GCSO's had the option to interact with MPATH using either the touchscreen or a mouse. This display was duplicated on the large-format video wall at the front of the ROAM UAS Operations Center.

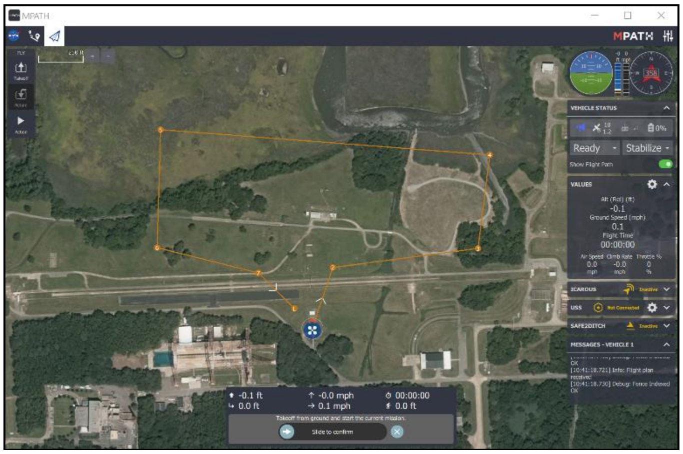

Fig. 3: MPATH GCS user interface.

4) xTM Client. Extensible Traffic Management (xTM) client is a traffic management tool built for fleet management functions. The tool allows for digital communication between a GCSO and a fleet manager to determine and allocate an operation timeslot and flight plan. Additionally, the GCSO workstation continually relays vehicle position data to be displayed on a map view with all other operations controlled by the fleet manager to indicate if the vehicle is conforming to the timing and volume assigned. For this simulation, the xTM client provided a means to indicate a vertiport closure, which signaled the fleet manager to execute a reroute function that generated a diversion flight plan, which could be obtained by the GCSO. The xTM client was displayed on a 27" monitor (portrait presentation), which was located to the left of the MPATH display (see Fig. 2). This display was duplicated on the large-format video wall at the front of the ROAM UAS Operations Center.

5) Eye Tracker. To measure GCSOs' eye movements, a screen-mounted Tobii Pro Nano eye tracker was used (off-body sensor). Eye movements were recorded at a sampling rate of 60 Hz and analyzed using Tobii Pro Lab software. GCSOs movements were unrestricted at the ROAM workstation. All eye movements were recorded in a quiet room with dimmed lights. Eye movement data were only recorded for glances toward the table-mounted touchscreen hosting MPATH. The eye tracker device was located at the top of the 24" touchscreen display hosting MPATH (see Fig. 2).

C. Automated Systems

1) ICAROUS. Independent Configurable Architecture for Reliable Operations of Unmanned Systems (ICAROUS) is an automated onboard system that provides the capability of midflight aircraft reroutes and communication to the vehicle autopilot. ICAROUS is a detect and avoid system that contains a suite of applications developed around core flight systems. The collection of these applications enables an onboard response to airborne traffic incursions and potential geofence breaches. For an in-depth review of ICAROUS see [10].

2) Safe 2 Ditch. Safe2Ditch is an automated onboard system that serves as a crash management resource. Safe2Ditch contains a preloaded set of ditch site locations with the position, size, and reliability of each ditch site. During an off-nominal event, the Safe2Ditch application can be turned on from the GCSO workstation, which allows the Safe2Ditch software to identify the best ditch site at that instance of time. The location of the ditch site is then communicated to ICAROUS, which generates a new flight path and communicates it to the autopilot for execution. For an in-depth review of Safe2Ditch see [11].

D. Simulated Scenarios

GCSOs piloted a simulated UAS through nine scenarios. Table I lists the simulated scenarios by number, scenario name, and systems in use.

TABLE I. SIMULATED SCENARIOS

No.	**Simulated Scenarios**	
	Scenario Name	***Systems in Use***
1	Vehicle Control Test	MPATH Only
2	Geofence Test	ICAROUS
3	Emergency Descent	MPATH Only
4	Nominal Flight Path	xTM client
5	Flight Path Deviation - (Low)	ICAROUS xTM client
6	Flight Path Deviation - (High)	ICAROUS xTM client
7	Landing Deviation – (Low)	S2D ICAROUS
8	Landing Deviation – (High)	S2D ICAROUS
9	Flight Path & Landing Deviation	xTM client

[a] MPATH was used for all scenarios.

1) Vehicle Control Test. This scenario tested the vehicle's ability to takeoff and begin autonomous flight, change modes, and execute a return to launch (RLT) command. It also tested a GCSO's ability to create a geofence and flight plan. A geofence is a virtual boundary indicating trajectory conflicts. Geofences are used to prevent a vehicle flying into restricted or unsafe airspaces.

2) Geofence Test. This scenario tests a vehicle encounter with a geofence and allows the onboard automated system (ICAROUS) to provide a new flight trajectory to avoid the geofence and then return to the original mission.

3) Emergency Descent. This scenario tests vertical descents with no horizontal movement. In this scenario, vehicle

altitude reduced at max descent rate of 1 meter per second from 375 feet to safely hold altitude at 175 feet.

4) Nominal Flight Path. This scenario tested a nominal flight executed using a predetermined flight plan.

5) Flight Path Deviation – (Low). This scenario tested a low threat traffic incursion that required ICAROUS to activate and reroute. Low threat refers to the intruder aircraft coming in on an approach for a nearby landing location.

6) Flight Path Deviation – (High). This scenario tested a high threat traffic incursion that required ICAROUS to activate and reroute. High threat refers to the intruder aircraft coming in on an approach for the same landing location. In this condition, the predicted loss of separation is greater than in the low condition.

7) Landing Deviation – (Low). This scenario tested a manually triggered low threat flight path deviation due to vehicle health issues. Low threat refers to the off-nominal condition timing being right after the vehicle finishes the departure leg of the flight path. The expected landing location is decided by Safe2Ditch software.

8) Landing Deviation – (High). This scenario tested a manually triggered high threat flight path deviation due to vehicle health issues. High threat refers to the off-nominal condition timing being right before the vehicle starts the arrival leg of the flight path, one of the furthest points from original takeoff location. The expected landing location decided by Safe2Ditch cannot be assumed with three landing locations in approximately equal proximity.

9) Flight Path and Landing Deviation. This scenario simulated a vertiport closure, where a GCSO required a new flight plan from the fleet manager mid-flight. These new flight plans were generated and scheduled within the xTM client.

E. Procedure

Participation in this study took two consecutive business days for each participant. Only one participant was tested at a time and the participant received a 1-hour lunch break each day of participation, as well as three 15-minute breaks each day. Upon arrival to the ROAM UAS Operations Center, the participant was asked to read and sign an informed consent form, privacy act notice, and a demographics and background information form. The participant then completed a short structured cognitive walkthrough. The next hour was spent familiarizing the participant to ROAM, the GCSO workstation, and the testing procedures. Following the familiarization session, the participant was asked to act as the GCSO across nine simulated UAS scenarios (approximately 20 minutes each). Before each scenario, the participant underwent an eye-tracker calibration process. Following each scenario, the participant completed a series of questionnaires (results from the questionnaires are not reported in this paper). At the conclusion of all scenarios across both days, the participant completed three post-experiment questionnaires (results from the questionnaires are not reported in this paper). At the end of each day, the participant was asked to engage in a debrief session, which lasted approximately 30 minutes. At the end of the second day the participant was thanked for their participation, which concluded their participation in the study.

F. Exploratory Analysis

The purpose of this study was to explore naturalistic eye glance behaviors of GCSOs in a novel work environment. As such, the experimental control necessary for inferential statistics was not present. Instead, the data captured are qualitative and descriptive. Additionally, because of the exploratory nature of the study, the eye tracking method was intended not to impair or impede the naturalistic behavior of the GCSO. This unobtrusive strategy allowed the GCSO to move around freely, look away from the touchscreen whenever they pleased, and modify the information displayed on the touchscreen as necessary. To better interpret the data, scenarios were grouped into categories corresponding with the system they were intended to test and the purpose of that scenario. Scenario number 3 was categorized as “Emergency Descent”, number 4 was categorized as “Nominal”, scenarios 5 and 6 were categorized as “ICAROUS”, scenarios 7 and 8 were categorized as “Safe2Ditch”, and scenario 9 was categorized as “xTM”.

It should be noted that the categorization of the scenario does not necessarily indicate the entire nature of the scenario. For example, the “ICAROUS” scenarios use both ICAROUS and xTM systems within the scenario. However, the GCSO only interacted with xTM for traffic awareness and was focused primarily on the behavior of ICAROUS. Another example is the “Safe2Ditch” scenarios which used both ICAROUS and Safe2Ditch. Again, although ICAROUS was enabled, the GCSO’s eye glance behaviors were primarily focused on the behavior of the Safe2Ditch function. Scenario 1 and 2 served as practice scenarios and system test scenarios and were not included in this analysis.

III. Results

A. Eye Tracking

Overall, there were variabilities in the proportion of time spent fixating on the touchscreen across scenarios (see Fig. 4). Participants fixated on the touchscreen the most during ICAROUS scenarios (scenario 5, 6; M = 46%, SD = 12.38), and the emergency descent scenario (scenario 3; M = 47%, SD = 11.18). Participants fixated on the touchscreen showing MPATH the least during xTM scenarios (scenario 9; M = 36%, SD = 4.63). The greatest variability between participants occurred within Safe2Ditch scenarios (7, 8; M = 43%, SD = 16.31) and the Nominal scenario (scenario 4; M = 41%, SD = 16.52). Fixations during the xTM scenario (scenario 9) also showed the lowest proportion of time fixating on the touchscreen showing MPATH.

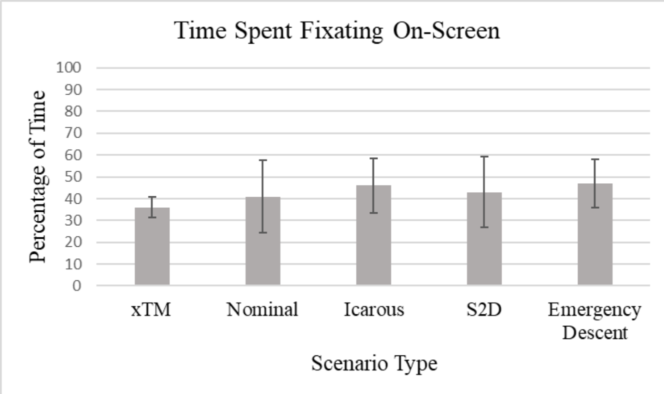

Fig 4. Proportion of fixations spent on the MPATH display across scenario type. Error bars represent standard deviation.

Throughout all scenarios, participants primarily viewed three AOIs: MPATH's map view (*M* = 42%), vehicle status (*M* = 32%), and the operations checklist (*M* = 12%; see Fig. 5).

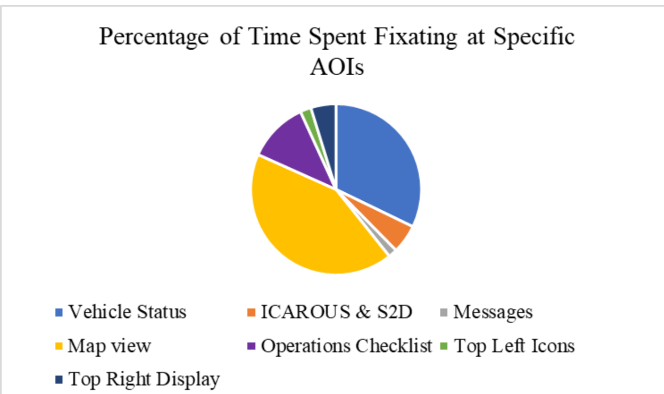

Fig 5. Proportion of time spent fixating at specific AOIs within MPATH and the GCS display.

Fixation distributions were further explored through visualizations such as heat maps (for an example of fixations during scenario 9, see Fig. 6). The heat map demonstrates the total number of fixations at specific locations on the display over the entire eye tracking session. For example, in Fig. 6, the GCSO fixated the most on the altitude information presented at the bottom of the screen. This is indicated by the bright red area on the heat map at that location.

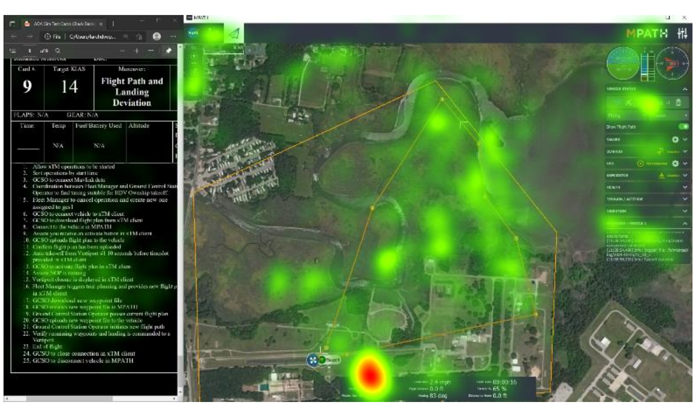

Fig 6. Heat map of a GCSO's fixations during scenario 9.

Additionally, participants' proportion of time spent fixating on the touchscreen decreased across the two testing days demonstrating a learning effect. Specifically, participants fixated 44% of the time on day one (*SD* = 4.30) and only 37% of the time on day two (*SD* = 4.70).

IV. Discussion

This study explored eye-glance behaviors of three GCSOs during simulated UAM scenarios within a remote operations center. The exploratory analysis of participants' gaze behaviors revealed several design improvements to the current GCS workstation and displays. First, the xTM display and MPATH display should be integrated or at least close in spatial proximity. Participants had to scan two separate displays over two different screens to complete their tasks. When the scenario required heavy interaction with the xTM display, participants had fewer fixations towards the MPATH display, a behavior that could result in change blindness [12] and impoverished situation awareness [13]. The potential benefits of integrating the two displays or placing them in close enough proximity that the participant can switch between them using only their eyes (i.e., without head movement) is supported both by the current data and theoretical models such as the proximity compatibility principle (PCP) [14]. One possible approach to integrating the two displays could be adding the traffic information found on the xTM display to the MPATH display.

Second, adding altitude information to the vehicle icon could further enhance scanning of the operator's vehicle. The AOIs the participants primarily scanned were the vehicle's trajectory on the map view, the vehicle status (including but not limited to altitude, ground speed, and ascent/descent rate information), and an operations checklist, which included the required procedure to complete the operation in MPATH. By integrating altitude information and potentially other telemetry data (e.g., speed) with the vehicles' icons, GCSOs could reduce splitting their visual attention and potentially reduce the likelihood of experiencing inattentional blindness [15].

Finally, each GCSO held their own visual allocation strategy when attempting to accomplish their task, even with a consistent operations checklist. Poor visual scanning strategies can promote mode awareness errors, but training may support more effective system monitoring [16]. Training should operationalize a consistent set of goals, declare which information can assist in achieving those goals, and set a precedence for how the GCSO should act. Operationalizing and standardizing such procedures may lead to more consistent visual scanning strategies.

There are some limitations to these findings. First, the nature of this study is exploratory and therefore little inference can be made statistically from this data. Secondly, the overall proportion of time participants glanced on-screen is likely lower than would be found in a non-simulated environment. To measure eye behavior, we used a screen mounted eye tracker that could capture glances only towards the touchscreen containing MPATH. The design of the GCSO workstation, missed data from the eye tracker, and off-screen scanning of

other information sources could have reduced the overall proportions of recorded on-screen glances.

Despite these limitations, we were able to generate several recommendations and conclusions. Future directions of this research will focus on innovating these systems and developing more direct hypotheses to explore in controlled laboratory studies. Specifically, we will employ other exploratory methods, such as hierarchical task analysis, cognitive task analysis, and other knowledge elicitation techniques, to explore and document the task structure and expertise of the actors within the system.

V. Conclusion

Using eye tracking data collected from three GCSOs, we identified a series of design improvements and training recommendations:

- The proximity compatibility principle should be applied to display design of the GCSO workstation wherever possible.
- Adding altitude information to the vehicle icon and traffic information within MPATH could help maintain the GCSO's visual attention towards the vehicle icon.
- Training should operationalize a consistent set of goals, declare which information can assist in achieving those goals, and set a precedence for how the GCSO should act.

Beyond our discovered design and training recommendations, we have built a foundation for our research to expand upon as we push towards BVLOS operations.

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